DURABILITY CHARACTERISTICS OF SELF-COMPACTING CONCRETE WITH PARTIAL SUBSTITUTION OF FOUNDRY SAND AS FINE AGGREGATE AND ADDITION OF PROPYLENE FIBERS

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Abstract- Foundry sand mainly consists of silicates, and it is used as a replacement of fine aggregate to make self-compacting concrete that is cheaper, better for the environment, and more durable. This research study looked at how foundry sand and propylene fibers (PPF) changed the mechanical and durability properties of self-compacting concrete. 25% cement was replaced with fly ash, fine aggregate is replaced with foundry sand in different proportions (0%, 20%, 30% & 40%) and propylene fibers in 0.75% were added. The goal was to determine the mechanical and durability properties of above-mentioned mixes of self-compacting concrete and to compare them with normal mix self-compacting concrete. The ratio adopted for the testing is of 1:1.56:2.60 (Binder: Fine Aggregate: Coarse Aggregate). For examining the mechanical characteristics of concrete, the tests carried out were splitting tensile strength, compressive strength, and Flexural strength tests. And to examine the durability properties water absorption, acid attack and abrasion resistance tests were conducted. The normal self-compacting concrete shows less resistance towards environmental effects. Experimental results show that the mix with 25% fly ash, 20% foundry sand replacement with addition of 0.75% of propylene fibers has performed better than all other samples including the control mix against environmental effects.

Keywords- Durability properties, Foundry Sand, Fly ash, Propylene fibers, Viscocrete, Mechanical properties.

1 Introduction

Self-compacting concrete (SCC) is a special type of concrete which can be placed and consolidated under its own weight without any vibration effort due to its excellent deformability, and which at the same time is cohesive enough to be handled without segregation or bleeding. The environment can have a significant impact on the durability of concrete. Various environmental factors can affect the physical and chemical properties of concrete, leading to deterioration over time. Foundry sand mainly consists of silicates, and it is used as a replacement of fine aggregate to make self-compacting concrete that is cheaper, better for the environment, and more durable.

Concrete is an important building material that is used all over the world. Concrete comprises water, cement, sand and small rocks. Researchers are trying to encourage builders to use natural pozzolanic materials as supplementary cementing materials (SCMs). Using SCMs, the carbon dioxide's (CO2) amount releasing into atmosphere during the cement-making process can be kept to a minimum [1]. Natural pozzolans can be used instead of cement in concrete because they have unique properties like low permeability, less heat of hydration, high sulphate resistance, and an enhancement to the ultimate concrete strength [2].

According to Gurpreet Singh and Rafat Siddique (2011), incorporating WFS (Waste Foundry Sand) as a partial replacement for sand in concrete results in increase in the USPV (Ultrasonic Pulse Velocity) values and a reduction in chloride ion penetration in concrete. These changes indicate that the concrete has achieved higher density and improved impermeability, enhanced strength properties, including compressive strength, splitting tensile strength, and modulus of elasticity [3].

Bavita Bhardwaj and Pardeep Kumar (2017) discovered that incorporating waste foundry sand (WFS) in concrete is beneficial. WFS possesses favorable material properties that contribute to the improved mechanical performance of concrete. Furthermore, the durability of concrete is enhanced when WFS is added up to an optimal level [4].

There are different individual studies carried out to study the impact of using foundry sand as fine aggregate and polypropylene fibers on self-compacting concrete's properties, no previous study has been carried out to analyze the environmental effect on durability of self-compacting concrete made by replacement of foundry sand as fine aggregate with addition of polypropylene fibers. This study examined the environmental effects on durability by i.e., Water Absorption, Acid Attack and Abrasion Resistance Tests of SCC made with foundry sand and PPF on concrete's and mechanical properties i.e., Flexural, Tensile and Compressive strength.

2 Experimental Procedures

2.1 Materials with their Properties and Mix Proportions

Fly ash (FA) and ordinary Portland cement, or OPC for short, were used as the binding ingredients in this research project. OPC type 1 cement, as specified by ASTM C150, was used [5]. Locally available foundry sand was purchased from the Heavy Mechanical Complex in Taxila, Pakistan. LawrancePur and Margalla, respectively, provided the fine and coarse aggregates. 19 mm long propylene fiber was used. Tap water was used for concrete mixing and curing. The superplasticizer, Ultra-Super Plasticizer 470 was added to concrete mixtures since foundry sand and PPF make the concrete less workable. The parameters of aggregate and PPF are shown in Tables 1 and 2, whereas the parameters for fly ash and sand from foundries are shown in Table 3.

Table 1. Physical properties of coarse and fine aggregates and waste foundry sand.

	Coarse Aggregate	Fine Aggregate	Waste Foundry Sand
Specific Gravity	2.68	2.62	2.24
Fineness Modulus	6.34	2.58	1.86
Water Absorption	0.6	1.5	1.7
Moisture Content	Nil	Nil	Nil

Table 2. Properties of Propylene Fiber.

Shape	Straight
Length (mm) l	12
Diameter (mm) d	0.019
Aspect Ratio (l/d)	631
Density (g/cm^3)	0.91
Elastic Modulus (GPa)	3.5
Tensile Strength (Mpa)	350

Table 3. Properties of Fly ash and Waste foundry sand.

1Chemical Compounds		Fly Ash		WFS
CaO %		2.92		1.65
SiO2		61.2		88.11
Al2O3		28.23		0.49
Fe2O3		3.9		2.38
MgO		0.93		0.76
SO3		0.73		-
Na2O		0.01		0.95
K2O		1.34		0.83
TiO2		-		0.1
Loss on Ignition (%)		0.74		0.73

The experimental schedule is shown in Table 4, which consists of comparing four different mixes. M1 denoted the control mix having OPC as the only binder, while M2, M3 and M4 denoted the mixes containing 20%, 30% and 40% foundry sand as fine aggregate replacement respectively. Poly propylene fiber was also added in 0.75% in M2, M3 and M4 respectively. Table 5 shows the mix design composition.

Table 4. No of Samples for testing

Mix	Mix Type	Disc	Cube	Cylinder	Cubes	Beams	Cylinder
M1	Control Mix (SCC)	6	6	6	3	3	3
M2	OPC (25% F.A) + 20% W.F.S + 0.75 % PPF	6	6	6	3	3	3
M3	OPC (25% F.A) + 30% W.F.S + 0.75 % PPF	6	6	6	3	3	3
M4	OPC (25% F.A) + 40% W.F.S + 0.75 % PPF	6	6	6	3	3	3
		Water Absorption	Acid Attack	Abrasion Resistance	Compressive Strength	Flexural Strength	Split Tensile Strength

Table 5. Mix Design Composition

Mix Design Proportions for M40 (1 : 1.56 : 2.60)					
Mix No.	**Cement + Fly Ash**	**Fine Aggregate + Foundry Sand**	**Coarse Aggregate**	**w/c**	**Propylene Fiber**
-	kg/m^3	kg/m^3	kg/m^3	-	%
M1	416.64 + 0	649.72 + 0	1082.72	0.5	0
M2	312.48 + 104.16	520 + 130	1082.72	0.5	0.75
M3	312.48 + 104.16	455 + 195	1082.72	0.5	0.75
M4	312.48 + 104.16	390 + 260	1082.72	0.5	0.75

2.2 Concrete Mixing

Every batch of concrete was mixed in three steps. In the initial phase, aggregates and binders were combined dry. In second phase, more than half of water was added to create a uniform mixture, while the part of water remained, along with superplasticizer were then added. PPF was incorporated in the end to avoid the clumping of fibers due to more revolutions of mixer.

2.3 Specimen and Testing

During the casting of samples, one layers of concrete were applied to every sample. Using ASTM C1611 procedure, the self-compacting concrete slump flow was determined prior to specimen casting [6]. For determination of mechanical characteristics of concrete samples Compressive strength test, splitting tensile strength test, and flexural strength tests were done. Based on BS standard EN-12390 [7], 150mm x 150mm x 150mm cube specimen were casted, and then tested for compressive strength after being cured for 28 days.

After 28 days of curing, 150mm x 300mm concrete cylindrical samples were tested for the split tensile strength in accordance with ASTM C496 criteria [8]. The beam specimens measuring 100mm x 100mm x 500mm were tested for flexural strength in accordance with ASTM C78 specifications [9]. The test setup for the durability properties is given in Figure 1. For determination of durability characteristics of concrete samples water absorption, acid attack and abrasion resistance tests were done. Based on ASTM C642 [10], 100mm x 50mm circular disc specimens were casted, and then tested at 28 days and 56 days for water absorption after being cured for 28 days.

After 28 days of curing, 100mm x 100mm x 100mm concrete cubical samples were tested for 28 days and 56 days for the acid attack. The cylinder specimens measuring 100mm x 500mm were tested for abrasion in accordance with ASTM C131 [11] specifications.

a) b) c) d)

Figure 1 Testing formation for (a) Slump flow test (b) Water Absorption (c) Acid Attack (d) Abrasion Resistance Test

3 Research Methodology

Four types of mixes were prepared in Laboratory. Slump flow test was conducted firstly to determine the fresh properties of SCC, then to find out the mechanical properties, compressive strength test, flexural test and split tensile strength were done and to find out the durability properties at 28 days and 56 days water absorption, acid attack and abrasion resistance in the laboratory after 28 days curing in water tank at normal temperature.

4 Results

4.1 Slump Flow

The workability of all the mixes was determined using slump flow apparatus based on procedure given by ASTM C1611. To create workable mixtures, varied amounts of superplasticizer were combined with a consistent water-cement ratio. Figure 2 displays the results of the workability of each mixture. The mix M2, M3, and M4 which has percentage of Foundry sand, fly ash and propylene fibers produced somewhat lower slumps than the control mix (M1). The reduction in mixes workability can be related with fineness of foundry sand as it more fine than fine aggregate. The addition of PPF to the mixtures has also significantly decreased their workability because the concentration of fibers enhances internal friction in mixtures with a constant amount of water added.

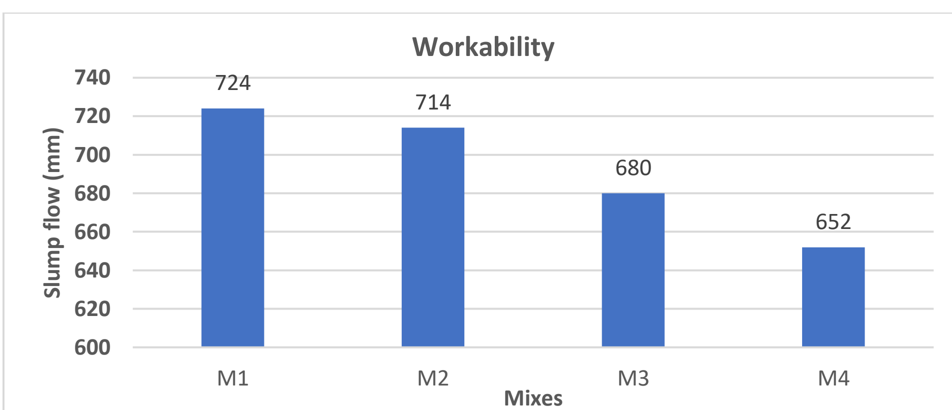

Figure 2: Slump Flow Test

4.2 Water Absorption

When it comes to durability, the water absorption of concrete is a critical parameter to consider since it indicates the level of porosity in the concrete that is accessible to water. A greater capacity for water absorption in concrete can lead to a more extensive infiltration of contaminated water, potentially having harmful chemicals, into the concrete. This can result in a shortened service life for the concrete. Water absorption testing was conducted on all four mixes after 28 and 56 days of curing. Results of this test are shown in Figure 3. From the results obtained it is noticed that water absorption was reduced by incorporation of foundry sand in the concrete. For mixture M2, the water absorption decreased by 4.2%, 10.4% at 28-day and 56-day respectively, in comparison with the mix (M1) that is control mix. The decrease in water absorption can be accredited to the formation of additional cementitious compounds from the pozzolanic reaction, fineness of foundry sand as well as the filler properties of fly ash, and addition of PPF to contract cracks.

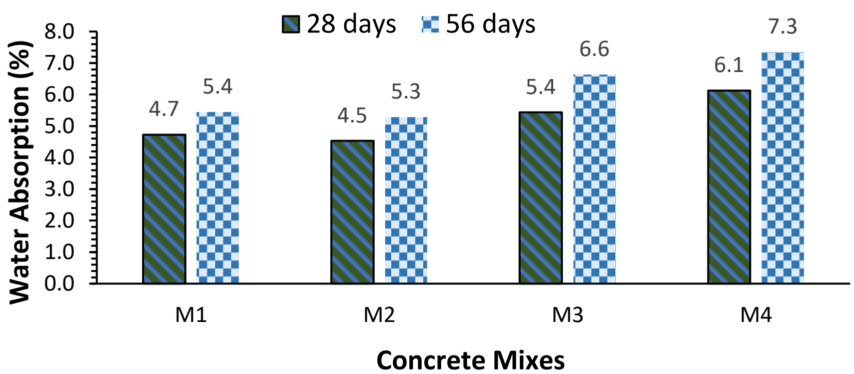

Figure 3 Water Absorption Test

4.3 Acid Attack

Figure 4 displays the weight loss incurred by all the mixes when exposed to a sulfuric acid solution for 28 and 56 days, indicating their acid attack resistance. Results show that 20% foundry sand incorporated mixes offered more resistance to weight loss against acid exposure than the control mix. After 28 and 56 days the mixes M2 resulted in 22.9% and 17.3% reduction in weight loss against abrasion respectively, when compared to the mix (M1). The control mix exhibited a higher weight loss, which may be attributed to the presence of a greater amount of calcium oxide, which can lead to the formation of gypsum, finally formation of ettringite occurs resulting in expansion and deterioration of concrete. The higher content of silicon dioxide, aluminum oxide, and ferric oxide in foundry sand may contribute to the production of more CSH gel through the pozzolanic reaction. The deterioration of concrete against acid exposure increased with time because of the deeper penetration of sulphate ions into the concrete mix resulting.

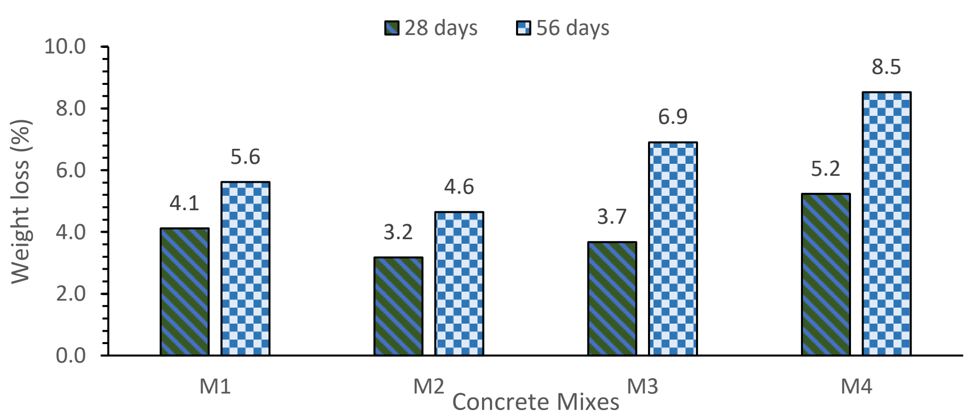

Figure 4 Acid Attack Test

4.4 Abrasion Resistance

The abrasion loss for all four mixes is shown in Figure 5. Incorporating foundry into the concrete consequences in an enhancement in the resistance of the concrete to abrasion. After 28 and 56 days the mixes M2 resulted in 40.9% and 45.8% reduction in weight loss against abrasion respectively, when compared to the mix (M1). Fig. 5 shows the specimen before and after performing the test. The pozzolanic reaction that occurs during the production of supplementary CSH gel can contribute to the development of a dense and uniform microstructure in the concrete, which may explain the increase in abrasion resistance observed in this study.

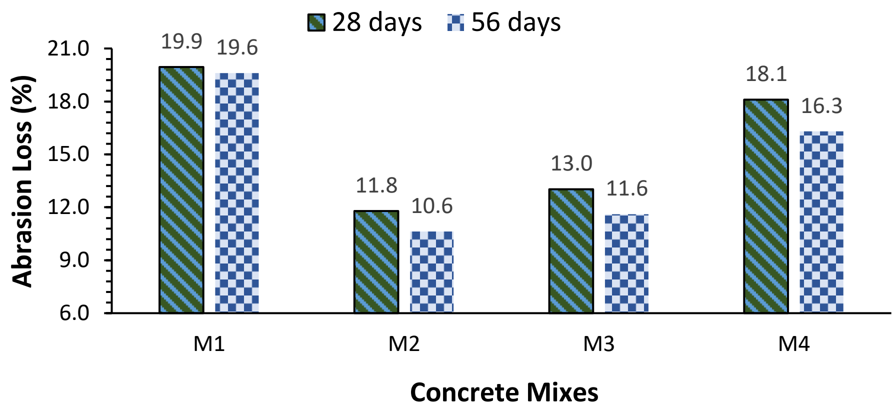

Figure 5 Abrasion Resistance Test

5 Conclusions

Based on the conducted experimental study, the study's findings lead to the following conclusions:

1- The workability of foundry sand incorporated mixes was lowered, while incorporation of Propylene fibers caused in further decrease of workability.

2- Use of foundry sand and fly ash with addition of polypropylene fiber has improved the mechanical as well as durability properties.

3- By addition of 25% fly ash, 20% foundry sand as fine aggregate with addition of 0.75% propylene fibers in SCC formation, the mechanical properties like compressive, flexural and tensile strength have been increased by 2.87%, 8.11%, and 3.48% respectively.

4- By addition of 25% fly ash, 20% foundry sand as fine aggregate with addition of 0.75% propylene fibers in SCC formation, the water absorption, acid attack and abrasion resistance has been improved by 4.2%, 22.9%, and 40.9% at 28 days and 10.4%, 17.3%, and 45.8% at 56 days, respectively.

5- The above results evidently shows that concrete with 25% replacement of cement with Fly ash, 20% replacement of fine aggregate with Waste Foundry Sand (WFS) and addition of 0.75% polypropylene fiber is found to be optimal mix for mechanical and durability characteristics.

6- The incorporation of high dosage 30% and 40% of foundry sand content resulted in degradation of the mechanical and durability characteristics of self-compacting concrete.

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References

[1] UN Environment, K.L. Scrivener, V.M. John, E.M. Gartner, Eco-efficient cements: Potential economically viable solutions for a low-CO2 cement-based materials industry, Cement and Concrete Research 114 (2018) 2–26
[2] "Use of Natural Pozzolans in Concrete (ACI 232.1R)," ACI Mater. J., 1994, doi: 10.14359/4060.
[3] Raffat Siddique, Effect of Used – Foundry sand on the mechanical properties of concrete, Construction and Building Materials 23(2009) 976-980.
[4] Bhupendra Singh Shekhawat(2007), Utilisation of Waste Glass Powder in Concrete, International Journal of Innovative Research in Science, Engineering and Technology
[5] ASTM C150 "ASTM C150 / C150M-19a Standard specification for Portland Cement", 2019.
[6] ASTM C143/C143M "Standard test method for slump of hydraulic-cement concrete", ASTM Standards, 2015.
[7] BS EN 12390-3 "Testing hardened concrete. Compressive strength of test specimens, British Standards Institution", https://www.thenbs.com/PublicationIndex/documents/details?Pub=BSI&DocID=288816.
[8] ASTM C496/C496M "Standard test method for splitting tensile strength of cylindrical concrete specimens", 2017.
[9] ASTM C78, "Standard Test Method for Flexural Strength of Concrete," Annu. B. ASTM Stand., 2016.
[10] ASTM C642 "Standard test method for density, absorption, and voids in hardened concrete", ASTM Standards (2013).
[11] ASTM C131/C131M "Standard test method for resistance to degradation of small- size coarse aggregate by abrasion and impact in the Los Angeles machine", 2014.